A VARIABLE QUADRAT REGENERATION SURVEY METHOD

By A. BICKERSTAFF¹

ABSTRACT

The theory and application of a variable quadrat technique which may be used to assess the adequacy of stocking in stands of young growth are described.

INTRODUCTION

The growing acceptance of relascope and other variable plot sampling techniques for the estimation of volume and basal area in merchantable stands led the author to consider whether comparable techniques could be developed for the assessment of regeneration. Preliminary study indicated certain theoretical advantages for a variable quadrat size in regeneration surveys, and a practical technique was developed and tested in the field. In this paper the theory underlying the technique is outlined, its application for field use is described, and some of the possible uses and interpretations of the data so obtained are briefly discussed.

The concept involved is that the area of the sample (quadrat size) must be proportional to the size of the regeneration sampled. For regeneration, the common measure of size is height, and the sampling scheme is designed so that the probability of an individual tree being included in the sample is directly proportional to its height. For example, the quadrat used to sample regeneration four feet in height is twice the size of that used to sample regeneration which is only two feet in height.

THEORY

The theoretical considerations necessary to achieve a sampling proportional to size are analogous to those for variable radius plots with the relascope. The principles applicable to the relascope have been described in detail by Grosenbaugh (1958), Kendall and Sayn-Wittgenstein (1959), and others. In general, the trees included in the sample are those whose measured dimension subtends an angle that is greater than a selected critical angle. For the measurement of basal area in relascope plots this angle is measured in a 360° sweep in a horizontal plane from a point, and the sampling is proportional to the square of the dimension measured, i.e. to the square of the diameter. If a 360° sweep from a point with an angle measured in a vertical plane is used to cover the height dimension, the sampling will be proportional to the square of the height. However, for regeneration sampling, sampling proportional to the height (not to the square of the height) is required, and this is accomplished by measuring in relation to a fixed vertical angle at right angles to a baseline of a fixed length rather than from a point.

In the following subsections, the method of selecting sample trees and a few simple functions which express the relationships existing between distance, height, area, linear feet, number of trees, number of samples, and per cent

¹ Forest Research Branch, Department of Forestry, Ottawa.

stocking are outlined. The symbols used throughout this paper to denote such quantities are:

- $H, H_1, H_2, \dots H_x$ = heights of trees sampled in feet.
 $R, R_1, R_2, \dots R_x$ = range or limiting distance in feet from baseline for trees of heights H, H_1 , etc.
 $A, A_1, A_2, \dots A_x$ = quadrat size in acres on which trees of H, H_1 , etc. are measured.
 $n, n_1, n_2, \dots n_x$ = number of trees qualifying of height H, H_1, H_2 , etc.
 θ = fixed vertical angle
 p = number of quadrats containing qualifying trees
 q = total number of quadrats in sample
 L = linear feet per acre
 N = number of trees per acre
 S = per cent stocking

Selection of Sample Trees

Only those trees whose heights more than subtend a fixed vertical angle measured from the horizontal at right angles along a baseline of fixed length qualify for inclusion in the sample. Qualifying trees, borderline trees, and other trees are shown diagrammatically in Figure 1.

Height, Distance and Area

By reference to Figure 2, the following relationships may be established:

$$\begin{array}{ll}
 \frac{R}{H} = \cot \theta & \frac{R_1}{H_1} = \cot \theta \\
 R = H \cot \theta & R_1 = H_1 \cot \theta \\
 A \text{ (acres)} = \frac{\text{area abcd}}{B.H. \cot \theta} & A_1 \text{ (acres)} = \frac{\text{area aefd}}{B.H_1 \cot \theta} \\
 & = \frac{43,560}{B.H_1 \cot \theta} \\
 \frac{H}{A} = \frac{43,560}{B. \cot \theta} & \frac{H_1}{A_1} = \frac{43,560}{B. \cot \theta}
 \end{array} \quad (1)$$

But with B a baseline of fixed length and θ a fixed angle

$$\frac{43,560}{B. \cot \theta} = k \quad \text{a constant value} \quad (2)$$

and

$$\frac{H}{A} = \frac{H_1}{A_1} = k \quad (3)$$

FIGURE 1. Selection of sample trees.

Linear Feet

Linear feet per tree = H

$$\text{Linear feet per tree per acre} = \frac{H}{A} = k$$

Linear feet of stemwood is a basic measure in variable quadrat regeneration techniques, since each tree that qualifies, regardless of size, represents a constant number of linear feet (k) per acre on a quadrat.

If q quadrats are established and n trees qualify on them, then

$$\text{Linear feet per acre} = L = \frac{n}{q} \cdot k \quad (4)$$

FIGURE 2. Relationship between height of tree, distance from baseline, and area of sample.

Number of Trees Per Acre

For trees of a particular height, say, H_1 having L_1 linear feet per acre, then

$$\text{Number of trees per acre} = N_1 = \frac{L_1}{H_1} = \frac{k}{q} \cdot \frac{n_1}{H_1} \quad (5)$$

For all heights,

$$\begin{aligned} \text{Number of trees per acre} &= N \\ &= \frac{L_1}{H_1} + \frac{L_2}{H_2} + \dots + \frac{L_x}{H_x} \\ &= \frac{k}{q} \cdot \frac{n_1}{H_1} + \frac{k}{q} \cdot \frac{n_2}{H_2} + \dots + \frac{k}{q} \cdot \frac{n_x}{H_x} \\ &= \frac{k}{q} \left(\frac{n_1}{H_1} + \frac{n_2}{H_2} + \dots + \frac{n_x}{H_x} \right) \quad (6) \end{aligned}$$

It should be noted that when several heights are present, the number of trees per acre *cannot* be determined by using the *average* height of the trees present and substituting in function 5.

Per cent Stocking

The per cent stocking of a particular size of tree is determined as in conventional stocked quadrat surveys, i.e. the number of quadrats stocked to that size is expressed as a percentage of the total quadrats established, i.e.

$$\text{Per cent stocking} = S = \frac{p}{q} \times 100. \quad (7)$$

It should be noted that comparisons of per cent stockings for different sizes of trees are subject to a unique interpretation because of the different-sized quadrats to which they apply. Every quadrat which has a qualifying tree on it represents at that point k linear feet per acre regardless of the size of the tree or the size of the quadrat. Thus, a per cent stocking of S means that S per cent of the samples support at least k linear feet per acre.

APPLICATION

To adapt the foregoing theoretical considerations to practical use, two things are required: First, the constant k which expresses the ratio between height and quadrat size and also the number of linear feet represented by one tree on one quadrat, must be set at some suitable value. Secondly, some simple field method must be devised for selecting the trees which qualify for sampling.

Selection of k factor

The k factor can be set at any value desired, but some values will be more convenient and useful than others. For convenience in computation, some power of 10 such as 100, 1,000, 10,000 or 100,000 has obvious advantages. If per cent stocking figures are to be used, it would be advantageous to have the k factor set at some stocking level in terms of linear feet of stems per acre so that any tree qualifying on a quadrat would indicate an acceptable stocking at that point.

To obtain information on levels of stocking in terms of linear feet per acre, data from a number of yield tables, notably for conifers in managed stands (Hummel and Christie, 1953), plus some natural stands, were transformed into this measure of stocking. From these data it would appear that linear feet per acre plotted over height usually approximates a straight line on double logarithmic paper. In them, values of linear feet per acre ranged from approximately 20,000 to 50,000 at heights of 20 to 30 feet and from 8,000 to 15,000 at heights of 80 to 100 feet. Wider ranges are encountered in unmanaged and irregular natural stands.

Using some power of 10, the value of $k = 10,000$ is the closest approximation to these ranges. With a quadrat stocked to one tree, k set at 10,000 would represent at that point one of the combinations of height, number of trees per acre, and quadrat size shown in Table 1.

For trees up to 10 feet in height, such levels of stocking, based on plantation experience, are more than adequate. From yield tables in observed natural stands, the stocking is also reasonable in the upper size classes. For the intermediate heights, 10,000 linear feet per acre would probably not fully utilize the growing capacity of the site. However, since the method is intended primarily for regeneration stands, it is evident that a figure of 10,000 linear feet per acre represents good stocking for them, and for larger material may approximate the minimum stocking permissible for optimum utilization of the site. Therefore, a k value of 10,000 is adopted.

Baseline and vertical angle

The required value of 10,000 for the constant k can be set by an infinite number of combinations of baseline length and vertical angle. Thus, if the

TABLE 1
RELATIONSHIP OF HEIGHT, NUMBER OF STEMS AND QUADRAT SIZE
($k = 10,000$)

Height in feet	Number of stems per acre	Quadrat size (acres)
1	10,000	.0001
2	5,000	.0002
3	3,333	.0003
4	2,500	.0004
5	2,000	.0005
10	1,000	.0010
20	500	.0020
30	333	.0030
40	250	.0040
50	200	.0050
60	166	.0060
70	143	.0070
80	125	.0080
90	111	.0090
100	100	.0100

baseline is set as some convenient unit of a standard measuring tape such as 5 feet or 10 links, the corresponding vertical angles will be $48^{\circ} 56'$ and $56^{\circ} 35'$ respectively. However, preliminary field trials with specially constructed angle gauges showed that it was impractical to define these angles, in relation to either large or small regeneration, with any degree of accuracy in a reasonable time. A 45° vertical angle is much more convenient and this corresponds to a base of 4.356 feet. (The length of the segment or base is computed from equation 2, by substituting $k = 10,000$ and $\cot 45^{\circ} = 1$.) For field use a tape was regauged into ten contiguous segments, each 4.356 feet in length, to provide the base for 10 variable quadrats.

The use of the 45° vertical angle permits a very simple and rapid method of selecting and checking qualifying trees—all trees closer to the baseline than their height qualify; those farther out do not. For most trees it is readily apparent whether they are in or out, and only a small proportion needs to be checked by measurement. To check regeneration, no angle gauge is required, since a measuring stick will immediately indicate whether the distance to the baseline is greater or less than the height. An Abney hand-level set at 45° provides a simple check on larger trees. Corrections for significant slope in the terrain are not a problem with smaller trees because a direct check is possible without the use of correction factors (see Appendix 1).

Size Classes

To obtain the number of stems per acre from a variable quadrat survey, the heights of the qualifying stems must be known (equation 6), otherwise stocking will be known only in terms of linear feet per acre. For most purposes, it is sufficient to record heights by height classes rather than as exact heights of individual stems, and for general use the following classes were adopted: below 0.51 foot—two size classes; between 0.51 and 5.5 feet—one-foot classes; and above 5.5 feet—10-foot classes. With very little practice these size classes can be estimated accurately on an ocular basis. The height classes and class limits are shown in Table 2.

TABLE 2
HEIGHT CLASSES AND LIMITS

Height Class (feet)	Class Limits (feet)
0.05	0.01 - 0.10
0.3	0.11 - 0.50
1	0.51 - 1.50
2	1.51 - 2.50
3	2.51 - 3.50
4	3.51 - 4.50
5	4.51 - 5.50
10	5.6 - 15.00
20	15.1 - 25.00
...	... - ...
100	95.1 - 105.00

Field procedure

All field layout and measurement can be done by one man, but it is more convenient to have two men per crew. The only special equipment required is a steel tape graduated into ten segments of 4.356 feet each, and two light-weight measuring sticks, approximately six feet long, graduated either in tenths of feet or into the height class intervals shown in Table 2. Standard items of equipment required are: Abney hand-level, compass, and tally book.

Each plot is 43.56 feet in length and consists of 10 contiguous quadrats, each having a base of 4.356 feet. The species and height class of each qualifying stem are recorded, either by individual quadrats or for the plot as a whole, depending upon the detail required (*see Discussion*). Qualifying stems are those whose heights more than subtend a vertical angle of 45° measured from a horizontal plane at ground level and at right angles to the baseline.

In the field, qualifying trees may be determined simply by the method shown in Figure 3. One observer tallies all qualifying trees which occur to

FIGURE 3. Field layout for a plot of ten variable quadrats.

AB = baseline of 43.56 feet with 10 equal segments.

AE = AD = eye-level height of observer with hand-level.

Qualifying trees are those:

On area ABCD: Any tree whose distance from the baseline is less than its height, i.e. trees whose tops extend above the plane ABJK.

On the indefinite area to the left of AB and at right angles to it: Any tree whose height is greater than AE (eye level of observer) and whose distance to the baseline is less than its height, i.e. trees whose tops extend above the plane EFGH.

right of the baseline and within a distance from it equivalent to the eye-level height of the second observer. The first observer requires no angle gauge, since doubtful trees are checked by a comparison of height and distance from baseline. The second observer moves along the baseline and tallies qualifying trees on the left-hand side; he checks doubtful trees by determining whether or not their tops intersect his line of sight through an Abney level set at 45° .

An alternative, and seemingly more direct method of selection is also evident from Figure 3. The second observer could move along the line CD (i.e. parallel to the baseline with his distance from it equal to his eye-level height), and tally all trees to right of CD which intersect his 45° line of sight. However, this method was found impractical because of the difficulty of maintaining the distance AD from the base and also because an adjustment in that distance was required as part of the slope correction.

A simple means of correcting for slope is given in Appendix 1.

A field test was made by the author and an assistant in a stand of white pine, red pine and mixed hardwoods which had a wide range of size classes as a result of an irregular shelterwood cut made ten years previously. A total of 15 plots, each containing 10 contiguous variable quadrats was established systematically throughout the stand at four-chain intervals. The data obtained from this test are used to illustrate the computations required.

Compilation

The form of tally used to record the field data is shown in Figure 4. The columns represent the height classes and the rows are the ten quadrats in each plot. Each specimen of each species was designated in the appropriate cell of the tally sheet by entering the species abbreviation, e.g. wP for white pine.

The initial compilation of the data was made on the field sheets by totalling for each species and height class the number of specimens tallied and the number of quadrats on which they occurred. The next step was to summarize all tally sheets to obtain for each species and height class the number of specimens and number of quadrats on which they occurred. The summary for maple is shown in Table 3. The number of linear feet per acre (L) is computed as from function 4. In this case with a constant k of 10,000 and 150 quadrats in the entire sample, the conversion to linear feet is obtained by multiplying the number tallied by the factor 66.66 and rounding the values to the nearest 10 feet. The number of trees per acre is obtained by dividing the number of linear feet by the appropriate height class. The total number of stems per acre for all height classes can be obtained by the summation of stems in the individual height classes. The number of stocked quadrats (p) is converted to a stocking per cent by dividing each value of p by the total number of quadrats (150) in the survey. The stocking percentages so derived represent the per cent of the quadrats on which at least 10,000 linear feet per acre occurs. This completes all of the basic computations. Subsequent computations depend purely upon the form in which the user wishes to have the final summaries for interpretation and analysis.

VARIABLE QUADRAT TALLY SHEET

PLOT No. 2 STAND No. 376 COMPARTMENT 35 LOCALITY Batawana S.C.S.

QUADRAT "K" FACTOR 10,000 MEASURED BY A.B. DATE 5 Oct 59

Species Tally by Height Class (feet)

Quadrat Number	0.05	0.3	1	2	3	4	5	10	20	30	40	50	60	70	80	90
1					WP											
2			WP	M												
3				M								O O				
4			WP M													
5			WP	WP												
6																
7				O M												
8			M M		O											
9						O M	M			WP						
10								M			WP					

Summary of Number Tallied and Quadrats Stocked (n-p)

	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p
WP	4/5	1/1	1/1						1/1	1/1	1/1				1/1	
PP												1/1	2/2		1/1	
A																
B																
O																
M	3/2	4/3	1/1	1/1	1/1	1/1					2/1	2/1				

TABLE 3

COMPUTATION OF NUMBER OF STEMS PER ACRE (N), LINEAR FEET PER ACRE (L), AND PER CENT STOCKING (S), FROM THE NUMBER OF STEMS (n) AND NUMBER OF STOCKED QUADRATS (p) TALLIED FOR MAPLE

Item		HEIGHT CLASS IN FEET								Σ_n	
		1	2	3	4	5	10	20	30		40
		n-p	n-p	n-p	n-p	n-p	n-p	n-p	n-p		
Plot	1					3-1	1-1	1-1		5	
"	2	3-2	4-3		1-1	1-1	1-1			10	
"	3	2-2	5-4		6-4	1-1		1-1		15	
"	4			1-1	6-3	7-5	15-5			29	
"	5		1-1	4-3	2-2	9-5	6-3			22	
"	6	1-1	2-2	2-2	1-1					6	
"	7						4-1	5-2	1-1	10	
"	8			1-1		1-1				2	
"	9				1-1	1-1	1-1			3	
"	10									—	
"	11	3-2	3-3	5-4		1-1	1-1			13	
"	12		1-1	1-1		4-2	1-1		1-1	8	
"	13				1-1					1	
"	14					1-1	4-4			5	
"	15	2-1	4-3	1-1			2-2	1-1	2-2	1-1	13
Σ_n		11	20	15	18	29	36	8	4	1	142
L		730	1330	1000	1200	1930	2400	530	270	70	9460
N		730	665	333	300	386	240	26	9	2	2691
Σ_p		8	17	13	13	19	20	5	4	1	
S		5	11	9	9	13	13	3	3	1	
		39					18				

An example of a convenient but rather detailed summary is given as Table 4. The linear feet per acre, number of stems per acre, and the relative stocking percentages are shown by individual species, all conifers combined, all hardwoods combined, and all species combined, by four size classes and for all size classes. The linear feet per acre and number of stems per acre in Table 4 are obtained merely through a routine addition of the data for various species which have been compiled as in Table 3. However, in case of the relative stocking percentages, a change in the height classes used for summarization and the combining of species requires the use of the combined stocking formula given by Bickerstaff and Matte (1961). In this formula, the combined stocking $S_{1,2,\dots,n}$ as a decimal fraction is $1 - (1 - S_1)(1 - S_2) \dots (1 - S_n)$.

TABLE 4
DISTRIBUTION OF LINEAR FEET AND NUMBER OF STEMS PER ACRE, AND PER CENT
STOCKING BY SPECIES AND SIZE CLASS IN A PINE-HARDWOOD STAND

		White Pine	Red Pine	Jack Pine	All Conifers	Aspen	Birch	Maple	Oak	All Hdwds.	All Species
Linear Feet per acre											
Under 0.5 feet height		1870	70	—	1940	—	—	—	—	—	1940
0.6 to 5.5 "		12380	130	70	12580	410	270	6190	1340	8210	20790
5.6 to 35.5 "		3940	530	70	4540	3060	270	3200	660	7190	11730
Over 35.5 "		3340	3600	260	7200	130	330	70	1070	1600	8800
All sizes		21530	4330	400	26260	3600	870	9460	3070	17000	43260
Number of Stems per acre											
Under 0.5 feet height		6233	233	—	6466	—	—	—	—	—	6466
0.6 to 5.5 "		6546	130	23	6699	116	92	2414	568	3190	9889
5.6 to 35.5 "		316	23	2	341	274	27	275	57	633	974
Over 35.5 "		59	62	5	126	2	6	2	22	32	158
All sizes		13154	448	30	13632	392	125	2691	647	3855	17487
Stocked Quadrats per cent											
Under 0.5 feet height		13	T	—	13	—	—	—	—	—	13
0.6 to 5.5 "		55	1	T	56	4	3	39	11	50	78
5.6 to 35.5 "		20	4	T	23	21	2	18	6	40	54
Over 35.5 "		28	29	2	50	1	1	1	8	11	55
All sizes		77	33	3	85	25	6	50	23	72	96

DISCUSSION

The variable quadrat method of regeneration survey differs from the conventional stocked quadrat method, in that the stocking percentages are subject to a different interpretation and the two additional quantities of linear feet per acre and number of stems per acre are available directly. The unique interpretation which can be placed upon the stocking percentages would appear to be an advantage rather than a disadvantage, i.e. regardless of size of tree or size of quadrat, the stocking percentages have the same meaning—they represent the percentage of quadrats which support a minimum of 10,000 linear feet per acre. Since this value is independent of size class, quadrat size, and species, it is possible to apply a simple conversion formula to it so that stocking values can be combined and summarized in any form desired. In the conventional form of stocked quadrat survey, species can be combined if the quadrats are of the same size, and provided the size of the quadrats does not differ greatly they can be converted to a stocking value for a common size. However, if stocking values for different sizes of trees are combined in the conventional method, the results tend to be meaningless; for example, a 10 per cent stocking of 80-foot trees has an entirely different meaning than a 10 per cent stocking of trees one foot high.

The variable quadrat method permits a detailed examination of small samples for small trees and of large samples for large trees, so that all are of equal weight. In the conventional stocked quadrat method a small percentage of the fixed area quadrats are usually made list quadrats so that an estimate of number of stems per acre can be made. For small seedlings this is an extremely time-consuming and laborious operation, and for larger trees very inaccurate because of the smallness of the sample.

If the end use of the data is such that stocking percentages are not required, or not required in the detail described above, the whole procedure can be greatly simplified and still provide linear feet per acre and number of stems per acre with equal precision. The simplification is effected by reducing the k value to 1,000, or in terms of the examples given in this paper, by using the plot of 10 quadrats as the basic unit rather than the individual quadrat. The field sheet (Figure 4) is then reduced merely to the number of stems by species and height classes for which a simple dot tally can be made. Each tree present on the plot then represents 1,000 linear feet and the number of linear feet in thousands for any plot is the total number of specimens tallied on that plot. The right-hand column in Table 3 shows such values for maple. The variation in stocking from plot to plot, i.e. the distribution of the stocking about the average value, is a measure of how the stocking is spatially distributed. Thus, high standard deviations or coefficients of variation would represent erratic distributions and low values even distributions.

If neither stocking percentages for small quadrats, nor number of stems per acre are required, then the method can be further simplified by merely counting the qualifying trees without regard to size to obtain linear feet per acre only.

An additional advantage also accrues from using a smaller k value (1,000) and larger base (43.56 feet). A plot of this size is a reasonable sample of a

particular area. Thus, for example, if one-half of the plots had a stocking greater than some acceptable minimum value, then 50 per cent of the area is stocked to this standard. This is a valid assumption for large plots but not for small quadrats, just as in the case of conventional stocked quadrat surveys where the quadrats must be grouped into larger plots before valid deductions regarding the percentage of the area stocked can be made. It would seem, therefore, that unless detailed studies of micro-distribution are envisaged the larger plot size is simpler to work with in the field, and yields more practical figures on spatial distribution.

When the variable quadrat technique is used in stands containing trees of merchantable size, estimates of volume may be required. Volume can be determined in several ways provided that the diameters of qualifying trees are recorded. If height class is recorded then the number of stems per acre in each class can be computed and the volume per acre is the product of mean volume per tree (found from conventional standard volume table) and the number of trees in the class. Should only the number of linear feet per acre be known without regard to distribution by height class, then the volume computation suggested by Strand (1958) might be used. In it volume is considered as the product of linear feet per acre, mean basal area of the sample trees, and a conversion factor.

SUMMARY

A simple method of regeneration survey using a variable quadrat size has been developed. The size of quadrat is directly proportional to the height of the stem sampled. Trees included in the sample are those whose heights more than subtend a vertical angle of 45° along a baseline. For a baseline of 4.356 feet, each qualifying tree represents 10,000 linear feet per acre, or 1,000 linear feet for a baseline of 43.56 feet. The number of stems per acre in any size class is the quotient of the linear feet in that class and the height. The volume per acre of trees of merchantable size can be computed if their diameters are recorded.

The theory and application of the method are described and the use of linear feet per acre as a measure of stocking is discussed.

REFERENCES

- BICKERSTAFF, A and L. MATTE. 1961. The combined stocking of multiple species combinations. *For. Chron.* 37(1).
- GROSENBAUGH, L. R. 1958. Point-sampling and line-sampling: probability theory, geometric implications, synthesis. Southern Forest Experiment Station, Occasional Paper 160.
- HUMMEL, F. C. and J. CHRISTIE. 1953. Revised yield tables for conifers in Great Britain. Great Britain, Forestry Commission, Forest Record No. 24, London. H. M. Stationery Office. 23 pp.
- KENDALL, R. H. and L. SAYN-WITTGENSTEIN. 1959. An evaluation of the relascope. Canada, Dept. of Northern Affairs and National Resources, *For. Br., For. Res. Div., Tech. Note* No. 77. 26 pp.
- STRAND, LARS. 1958. Sampling for volume along a line. *Meddelelser fra Det Norske Skogforsoksvesen* (Reports of the Norwegian Forest Research Institute). 15(3): 325-331.

APPENDIX 1 — SLOPE CORRECTION

Method 1

- (a) Pivot the baseline at its midpoint so that it is directly up and down the slope.
- (b) Correct its length if necessary according to standard slope chainage practice.
- (c) No correction to vertical angle or height/distance ratio is then required.

Method 2

- (a) Baseline at any angle to slope.
- (b) All trees small enough to be measured with a pole qualify if their height is greater than their horizontal distance to the baseline.
- (c) For trees checked by the angle gauge, the critical angle of 45° must be adjusted for the degree of slope in the direction of the sight as in the correction chart (Figure 5).

Method 3 (approximate)

- (a) and (b)—As in Method 2.
- (c) For trees checked by angle gauge, estimate the difference in elevation between ground level at the observer and at the base of the tree. Add or subtract this difference to the top of tree by ocular estimate in comparisons with the 45° line of sight.

**A Few More Complete Sets of
1960 ANNUAL MEETING PAPERS**

— 24 Papers —

can be obtained from the

CANADIAN INSTITUTE OF FORESTRY

10 Manor Road West, Toronto 7, Ontario

Cost \$3.00 per set

SLOPE CORRECTION FOR VERTICAL ANGLE

*

Computed from:
 $\tan(e+b) = \tan e + \tan a$
 $\tan(e-b) = \tan e - \tan a$

where:

e = Vertical angle (45°) on level ground
 a = Angle of slope
 $e \pm b$ = Vertical angle corrected for slope a

FIGURE 5. Slope correction chart.